A Conceptual Model for Determining the Highest Potential Payoff Areas for NASA Aeronautics Investments

A White Paper by Herman A. Rediess

1.0 BACKGROUND

The aeronautics industry and aviation community served by NASA R&D investments in aeronautics is large, diverse and varied in their interests and priorities for technology. The stakeholders of NASA research and technology include: the aeronautics industry (both commercial and military), including subsystems suppliers and venders as well as the airframers and engine manufacturers; DoD; FAA; the airlines; aircargo companies; other commercial and private aircraft owners and operators, including rotocraft; and, indirectly, the traveling public, recipients of aircargo and US residences in general from the positive impact on the balance of foreign trade. To determine the total payoff of NASA research and technology investments, one would have to quantify the benefits to each of these stakeholders derived from each of the resulting technologies.

The task of determining the highest payoff areas is somewhat easier, because it is only necessary to develop measures, of the relative potential benefits resulting from R&D investments and not the absolute benefits to all stakeholders. Selecting the best metrics to apply across the diversity of NASA's program is the real challenge. How does one rank the benefits of flight safety for the traveling public vs increased market share for US transport manufacturers, or rank the benefit of improved controllability at extreme angles-of-attack in a fighter aircraft using thrust vectoring vs GPS landing approach guidance for General Aviation aircraft? It seems reasonable that the payoff function must be multi-dimensional and include qualitative as well as quantitative metrics.

Selecting metrics of potential benefits from a specific technology is complicated by the fact that the path technology takes from NASA R&D to product implementation is sometimes difficult to trace and to quantify the contribution made by NASA's investment. Usually many people and organizations outside NASA or NASA sponsorship have contributed to the technology by the time it is implemented. Also the final product may contain multiple new technologies that collectively produce the measurable benefit. It would be desirable to identify measures that are relatively insensitive to these factors.

The term, "Payoff", implies some benefit for the resources invested, like return on investment in the commercial world. Therefore, it is necessary to quantify the investment made. One must include both the technology R&D and implementation investments. In addition to NASA's R&D investment, which includes facilities, capital equipment and personnel costs as well as R&D funds, there are industry investments for technology transfer, RDT&E, possibly for capital equipment, and certification; and possibly other Government investments by FAA or the

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military for infrastructure changes needed to exploit a new technology for operational improvements.

The model considered here is intended for use in establishing priorities within NASA's R&D budget among proposed programs, which may include ongoing programs. This helps in formulating a model(s) because one can segment the process at a high level where decisions are based more on National priorities and politics than the relative payoff of the investment based on one metric across all proposed programs. NASA's support to military aircraft developments and technology has been dictated primarily by priorities on Defense spending by Congress than any measure of potential military payoff from NASA's investment vs civil payoff from a non-defense
technology investment. In such a case the important metrics may be totally incompatible. For example, if survivability through application of stealth technology is the highest potential payoff for a military support program, how can one rank that vs subsonic transport technology that reduces an airlines direct operating costs? On several occasions Congress has directed NASA to perform certain aeronautics programs because of National priorities. For example, in response to the oil crisis of the mid '70's, Congress directed NASA to develop a major aircraft fuel conservation technology program; and, in the late '70's directed NASA to develop a joint Cockpit Display of Traffic Information with FAA in response to highly publicized near mid-air collisions.

This White Paper presents a conceptual multi-dimensional model for determining the highest potential payoff areas for NASA's aeronautics investment. At the highest level, the model is a weighted collection of models for each compatible segment of the program in terms of relative National and/or political priorities and metric(s) for payoff. Examples of program segments are: subsonic transport aircraft technology; rotorcraft technology; etc. Each segment model would be used to rank the benefits within that program segment. Since the important metrics used in the models are likely to differ among the segments, i,e,. subsonic transports vs high performance military aircraft, the overall model provide a multi-dimensional payoff function rather than a simplistic scalar ranking of potential payoffs across the segments. Criteria are established for selecting those areas of highest potential payoff. The criteria can include qualitative as well as quantitative metrics.

The scope of this effort does not allow development of models for every segment of NASA's program; however, a model for the subsonic transport area (segment) is developed to illustrate the modeling approach. The factors to consider in formulating models for every segment are discussed such that the reader may develop models for the other segments.

2.0 METHODOLOGY

The methodology first segments the NASA R&D program into elements which have common bases for National and political priorities and for which consistent and valid metrics can established within the segments. Then models are developed for each segment that can be used to rank the relative payoffs technologies within that segment based on metrics that are most important and valid for that segment. Once the models are developed, they can be used to advocate one segment vs another by showing that the proposed R&D program will indeed produce high payoffs for that segment, or used collectively with weighting factors among the segments to select the highest payoff areas across the entire NASA Aeronautics Program.

2.1 Program Segmentation

NASA segments its aeronautics R&D program into elements which respond to their understanding of National priorities. The segmentation suggested here is close to the current NASA segmentation but expands it as follows:

1. Subsonic Transport Aircraft (passenger and cargo, including military)
2. High Speed Civil Transport Aircraft
3. High Performance Military Aircraft (excluding hypersonics)
4. Hypersonic Aircraft
5. Rotorcraft (military and civil)
6. Commercial Short-Haul Transport Aircraft
7. General Aviation Aircraft (including business and private)
8. High-Altitude Long-Duration Aircraft (excluding military UAVs)
9. Research and Technology Base (not specific to any other element)

The primary reasons for this segmentation are the following:

1. **Subsonic Transports** are the single largest contributor to the positive balance of trade within the aeronautics and the economic metrics can be clearly established. Military transports have some unique requirements, such a short and unimproved runway operations, but for the most part the metrics for commercial operations are equally important to the military, e.g., direct operating costs, etc.

2. The highest priority R&D for **High Speed Civil Transport** are addressing enabling technologies and environmental constraints and the potential market is uncertain, which causes a high degree of speculation in economic metrics.

3. **High Performance Military Aircraft** investment decisions are dictated by National Security priorities and the most important payoff metrics are dominated by military operational requirements and not financial return on investment type metrics.

4. **Hypersonic Aircraft** investment decisions are dominated by operational requirements (or lack of) for military applications or economical viability for civil applications. Military payoff metrics would depend on operational requirements yet to be determined. There are too many technical and operational infrastructure uncertainties to establish meaningful

metrics for civil applications at this time. A successful technology demonstrator vehicle program (e.g., NASP) would be required before military or civil applications could be reasonably considered. Decision on a technology demonstrator vehicle is clearly a National budget priority issue.

5. Most **Rotorcraft** technologies considered for NASA investment are common to both military and civil applications, therefore it is reasonable to consider them together. Since the technologies are common, common payoff metrics should apply. Budget decisions are heavily influenced by National security priorities, since over 70% of the market is for military vehicles. Balance of trade is a factor, but not to the extent that it is for subsonic transports, because of a much smaller world market .

6. **Commercial Short-Haul Aircraft** is a unique segment, in that there is essentially no US manufacturing industry to benefit from a NASA R&D investment in aircraft technologies. However, US operators can benefit from NASA R&D in safety and airspace system capacity.

7. Non-technical issues have dominated R&D investment decisions for **General Aviation Aircraft**, as defined here (excluding commuters and rotorcraft), since the late '70's, when the market for personal aircraft was devastated by liability issues. Recently there appears to be a modest market recovery. During the '80's the US GA industry was so devastated that they could not afford to incorporate new technology, and NASA's investment was minimal. The GA industry is in much better financial condition today and, with an improving market outlook, technologies that could increase the market or market share, would be considered. The driving factors in GA today are affordability and accessibility to a broader customer base.

8. **High-Altitude Long-Duration Aircraft** is a unique category for science platforms and limited experimental applications and has uncertain commercial markets. At this time payoff metrics would be in terms of performance and payload.

9. **Research and Technology Base**, as defined here, would be a portion of the budget that expands the understanding of aeronautical science and engineering and develops new innovative technologies in which the potential payoffs may not be fully substantiated a priori. Any of the models developed for the preceding segments might be used to estimate potential payoffs to the degree necessary to prioritize the elements within the segment.

The diversity of factors that are most important in determining payoff within each segment of NASA's Program, illustrates why a single scalar metric for payoff would not be valid for ranking the technology areas across the entire Program.

2.2 Potential Payoff Metrics

Potential payoff metrics should have the form, Metric = (Benefit)/(Investment), and both "Benefit" and "Investment" should be quantifiably related to the technology expected to result from NASA's investment. This is difficult for several reasons: 1) benefits are multi-dimensional and accrue to multiple stakeholders; 2) the investment includes many cost factors in addition to the NASA Aeronautics R&D dollar investment; 3) the benefits and investment can not easily be quantified directly in common units, i.e., dollars; 4) the specific contribution of NASA's investment as compared to industry investment in a technology is difficult to quantify; and, 5) the contribution of a specific technology to benefits can be difficult to quantify. To minimize these difficulties, it is suggested that metrics be developed for each segment of NASA's Aeronautics Program rather than trying to develop one set that would be valid across all segments. The next two subsections discuss the potential benefits and investments factors in general and the third subsection addresses the Subsonic Transport Aircraft segment in particular as an example of how valid metrics could be developed for each segment.

The scope of this effort is not sufficient to develop metrics for every segment. In fact, the metrics should be developed considering the most important payoff factors at the time they would be applied, because those factors can change with changing priorities within the segments.

2.2.1 <u>Potential Benefits</u>. Table 1 summarizes the stakeholders and potential benefits for NASA aeronautics investments. The potential benefits and candidate measures for the benefits are discussed in subsection 2.2.1.1 for civil applications, 2.2.1.2 for military applications, and 2.2.1.3 for universities. The benefits are classified into direct and indirect by the following definitions:

> **Direct benefit** [●], means that the stakeholder could potentially benefit directly for applying the technology or research.
>
> **Indirect benefit** [❍], means that the stakeholder could potentially benefit indirectly from a third party applying the technology or research. For example, if a commercial aircraft company implements a "more electric aircraft technology", it can create an increased sales potential for electric subsystems manufacturers even if no new subsystems technology is involved. Another example might be a hypothetical situation in which NASA sponsored technology made GA aircraft as easy to fly as driving a car and at a low cost, resulting in a growth in GA aircraft sales, all the GA subsystems and components companies would benefit indirectly from the increased market for their products even if not associated with the enabling technologies. Of course, the GA manufacturers and the enabling technologies companies would benefit directly from the NASA investment.

Table 1 Summary of Potential Benefits for NASA Aeronautics Stakeholders

POTENTIAL BENEFITS

STAKEHOLDERS	INDUSTRIAL FINANCIAL							EMPLOYMENT				BUSINESS/SOCIAL					NATIONAL/POLITICAL				
	Operating Costs	Net Profit	Sales	Market Share	ROI	Recovery Time	Investment Reduction	Number of Jobs	Wages	Benefits	Career Advancement	Flight Safety	Flight Convenience	Affordability	Passenger Satisfaction	Environment	National Security	National Pride	Gross Domestic Product	Balance of Payments	Congressional Interests
CIVIL APPLICATIONS																					
Aeronautics Industry																					○
Airframe Mfg Companies		●	●	●	●	●	●														
Engine Mfg Companies		●	●	●	●	●	●														
Subsystems & Components Companies		○	○	○	○	○	○														
Avionics Companies		●	●	●	●	●	●														
Other Suppliers		○	○	○	○																
Aircraft Owners & Operators																					○
Commercial Airlines	●	●		●	●	●						●									
Commuter Airlines	●	●		●	●	●						●									
Cargo Airlines	●	●		●	●	●						●									
Business Aircraft	●											●	●	●							
Airservice & Charter Companies	●											●									
Law Enforcement Agencies	●											●		●							
Emergency Airlift Organizations	●											●		●							
Private Aircraft Owners	●											●	●	●							
FAA	●						●					●									○
General Public																					○
Aircraft Passengers												○	○	○	●						
Recipients of Aircargo													○	○							
Aeronautics Industry Employees								●	●	●	●										
Aviation Community Employees								○	○	○	○										
US Residents in General																●		○	○	○	
MILITARY APPLICATIONS																					
Aeronautics Industry																					○
Airframe Mfg Companies		●	●	●	●	●	●														
Engine Mfg Companies		●	●	●	●	●	●														
Subsystems Companies		○	○	○	○	○	○														
Avionics Companies		○	○	○	○	○	○														
Other Suppliers		○	○	○	○																
DOD Aviation Segments	●						●										●				○
General Public																					
Aeronautics Industry Employees								●	●	●	●										
DoD Aviation Community Employees								○													
US Residents in General																●	○	○	○	○	
UNIVERSITIES																					○
Faculty								●	○	○	○										
Students								●	○												
Institution	○						○														

Aviation Constraints. Two areas in which NASA R&D produce benefits seem to be somewhat different than others: safety and environmental issues. Both impose fairly strict constrains on technology implementation, in that one must show that a new technology would not decrease safety or increase pollution (emissions and noise). As long as an "acceptable level" of safety and pollution are maintained, there is little benefit perceived by the aviation community for investing in safety or environmental technology, particularly if it increases the cost of operations or uses funds that could be used for improved performance or some other benefit. The "acceptable level of safety" is that level generally accepted by user community, e.g., the traveling public for commercial transports and commuter aircraft, GA pilots for GA, etc. The "acceptable level of pollution" is that level which the general public is willing to accept without putting pressure on the Government to reduce it. When the user community or the public becomes aware of a safety or environment issue, there could be a high payoff of NASA investment in technology. Subsection 2.2.3.2 gives examples of qualitative metrics for safety and environmental issues.

2.2.1.1 *Civil Applications*

a. Aeronautics Industry.

1. ***Airframe Manufacturing Companies***, including commercial transports, civil rotary-wing aircraft, commercial and privately-owned helicopters (including law enforcement and emergency vehicles), and Business and General Aviation (GA) aircraft. Commuter aircraft (under 100 seats) are not included since they are all foreign manufactured.

   Benefits - All US airframe manufacturing companies can potentially receive the following benefits depending on whether the NASA R&D is applicable to their products, i.e., transports, helicopters or GA:

   1.1 **Financial** - measures include: net profit; sales; market share; return on investment (ROI); and recovery time of investment to commercialize. These are the most direct benefits and quantifiable, although the contribution of NASA R&D to the final benefits may be difficult to trace and quantify.

   1.2 **Unique Facilities** - measure: investment reduction. Industry clearly benefits from unique NASA facilities. e.g., wind tunnels, large motion simulators, research aircraft, Numerical Aerodynamic Simulator, etc., but quantifying the benefit to "the industry" would be difficult. The benefit would have to be spread across all companies that would benefit and credited across all the technologies that result from use of the facility.

   It seems like the proper measure would a reduced investment (capital and operating expense) on the part of industry to provide necessary facilities if NASA did not have them. Many of the unique NASA facilities, would not be viable for each company to develop and operate on their own, because of low utility rate by any one company. NASA, as user and custodian of unique facilities for industry use, provides a convenient way to spread the utility across the industry avoiding possible antitrust and proprietary rights problems.

1.3 **Staff Capabilities** - measure: investment reduction. The benefits come from improving the staff qualifications and expertise with less investment from industry, through NASA R&D contracts and availability of graduate students trained under NASA grants. To first order, the investment reduction due to having NASA R&D contracts could be equated to the contract price less fee and G&A costs, which the amount if funded as IRAD. It might be appropriate to discount the investment savings by some factor that would account for inefficiencies in the NASA R&D contract process vs focused industry IRAD projects.

It would be difficult to quantify the investment savings to industry from NASA university grants. Several aircraft companies have active university involvement now. If there were no NASA university grants, how much of that investment would industry pick up? The answer is not clear. If the availability of quality graduate students decreased below the demand due to lack of NASA research grants, industry would probably increase their university investments. It is probably reasonable to exclude benefits to industry from university grants in the model because they will not be significant in determining the high payoff areas, even though industry does receive important and necessary benefits from the NASA university programs.

2. ***Engine Manufacturing Companies***, including turbojet and turbofan engines (GE, P&W, Garrett Engine Division of AlliedSignal, Allison Gas Turbine Division of General Motors and Textron Lycoming), turboprop engines (Garrett Engine Division of AlliedSignal, Allison Gas Turbine Division of General Motors and GEAE Small Aircraft Engine Operation), and piston engines (Textron Lycoming, Williamsport Plant, others?).

Benefits - All US aircraft engine manufacturing companies can potentially receive the following benefits depending on whether the NASA R&D is applicable to their products, i.e., turbojets, turbofans, turboprops or piston engines:

2.1 **Financial** - measures include: net profit; sales; market share; ROI; and recovery time of investment to commercialize. Same as 1.1.

2.2 **Unique Facilities** - measure: investment reduction. Same as 1.2.

2.3 **Staff Capabilities** - measure: investment reduction. Same as 1.3.

3. ***Subsystems Companies***, including electrical, hydraulic and pneumatic power and distribution systems, actuation systems, environmental control systems, fuel management systems, engine control systems, landing gear systems, nose-wheel steering systems, braking systems including wheels and tires, anti-icing systems, oxygen systems, and others.

   Benefits - Subsystems technology is generally not a major part of NASA R&D program. There have been programs on brakes and tires, anti-icing, landing gear systems, engineer controls, actuation systems, and others but support for such R&D is spotty. When NASA has subsystems technology programs, the following benefits are applicable to that part of the industry:

   3.1 **Financial** - measures include: net profit; sales; market share; ROI; and recovery time of investment to commercialize. Same as 1.1.

   3.2 **Unique Facilities** - measure: investment reduction. Same as 1.2. This applies to technologies that require unique facilities not available in industry, such as an aircraft equipped to test anti-icing concepts or one to test a new electric actuation system, etc.

   Subsystems companies probably benefit similar to aircraft and engine manufacturers in staff capabilities but it is less likely that this segment of the industry would make up NASA investment with company investments.

   Indirect benefits to subsystems from aircraft or engine technology from increased market opportunities can be included in the Financial measures.

4. ***Avionics Companies***, including guidance and navigation systems, flight control augmentation systems and autopilots, automatic landing systems, flight management systems, cockpit instruments, communications systems (voice and data-links), radar systems, and others.

   Benefits - NASA has a long history of R&D in avionics and related technologies under names of controls, flight management, human factors, and air transportation. When NASA has avionics technology programs, the following benefits are applicable to that part of the industry:

   4.1 **Financial** - measures include: net profit; sales; market share; ROI; and recovery time of investment to commercialize. Same as 1.1.

   4.2 **Unique Facilities** - measure: investment reduction. Same as 1.2. This applies to technologies that require unique facilities not available in industry, such as the Langley Research Center Transport Systems Research Vehicle or the Man Vehicle Systems Research Facility at Ames.

4.3 **Staff Capabilities** - measure: investment reduction. Same as 1.3. There are sufficient R&D contracts to avionics and related companies for these benefits to be significant and quantifiable.

Indirect benefits to avionics and related companies from aircraft and engine technology from increased market opportunities can be included in the Financial measures.

5. ***Other Suppliers,*** including all the component and materials required for aircraft, engines, systems and subsystems manufacturing that are obtained out-of-house.

Benefits - Benefits to this segment of the industry would most likely be indirect from an increased market for their products due to technology implemented by other segments. For example, the NASA R&D investments in composite materials applications to aircraft and engines has increased the market for composite materials suppliers.

5.1 **Financial** - measures include: net profit; sales; and ROI.

b. Aircraft Owners and Operators (U.S.)

6. ***Commercial Airlines***.

Benefits - The primary benefits to commercial airlines from NASA aeronautics investments are through reduced operating costs from more efficient aircraft and operating procedures and reduced maintenance costs. Some technology has been directed towards reducing the development costs of transport aircraft, e.g., numerical aerodynamic simulation to reduce wind tunnel time and costs, but the cost of implementing other technologies that reduce operating costs have more than offset any savings and the purchase price of transports continue to rise. Any savings in developmental costs due to new technology will be credited to the manufacturer not the airlines.

6.1 **Financial** - measures include: direct operating cost (DOC) per available seat-mile (ASM); net profit; ROI; and recovery time of investment to acquisition and implementation costs (RT). Sales and market share among airlines appears to be more a function of ticket price, advertising and promotions than advanced technology. RT is an important measure for airlines when considering a new technology upgrade, such as avionics. An United Airline Vice President told the author that their company would not add or upgrade avionics systems unless the payback of their investment was less than two years.

7. ***Commuter Airlines***, including fixed-wing aircraft and helicopters operating as commercial commuter services.

Benefits - Commuter airlines would benefit from new technology similar to commercial airlines, however, since most of the fixed-wing commuter aircraft are foreign manufactured, NASA does not tend to have aircraft or systems R&D programs for that segment of the industry. The carriers that use US manufactured helicopters and the GA (7 to 10 passenger) aircraft benefit from NASA R&D in the same way as commercial airlines. Research that improves efficiency of operations within the air transportation system would benefit all US airlines financially regardless of who manufactured the aircraft.

7.1 **Financial** - measures include: direct operating cost (DOC) per available seat-mile (ASM); net profit; ROI; and recovery time of investment to acquisition and implementation costs (RT). In this case ROI and RT apply mainly the carriers who use US manufactured aircraft or systems.

8. ***Cargo Airlines***, including all regularly scheduled aircraft operating primarily for cargo transportation and express mail couriers, e.g., FedEx, UPS, etc.

   Benefits - The benefits should be about the same as for commercial airlines.

8.1 **Financial -** measures include: direct operating cost (DOC) per available ton-mile (ATM); net profit; ROI; and recovery time of investment to acquisition and implementation costs. Sales and market share among cargo carriers appears to be more a function of shipping price, service and advertising than advanced technology.

9. ***Business Aircraft***, including corporate aircraft (fixed- and rotary-wing) and individually owned aircraft used for business purposes, e,g., corporate operated airservices, professional persons using a small airplane for business travel, and news media aircraft.

   Benefits - Purchase price and operating costs are major factors in selecting aircraft for business purposes. The Business aircraft operations that use US manufactured helicopters and the GA aircraft benefit from NASA R&D in the same way as commercial airlines. In the case of civil use helicopters and GA aircraft, NASA R&D programs can include technology to reduce acquisition costs and possibly actually impact the cost of aircraft in the future. Research that improves efficiency of operations within the air transportation system would benefit this segment of the aviation community financially regardless of whether the aircraft are US or foreign manufactrued. In the case of news media aircraft, safer operations at low altitude over metropolitan areas is particularly important and they would benefit from NASA R&D to improve such safety, e.g., low cost GPS-based traffic situation awareness systems and wire detection systems for helicopters. There is a tendency for professionals who fly there own airplane for business purposes, to risk flying in marginal weather conditions than advisable for the aircraft and systems onboard. Such aircraft would benefit from technology to provide improved real-time weather information in the cockpit. The benefits would be improved safety and efficiency for the professional, i.e., fewer delays and aborted trips due to weather, which may be difficult to quantify.

9.1 **Financial** - measures include: direct operating costs (DOC) per mile, including amortized capital investments; and cost savings due to business efficiency.

10. ***Airservice and Charter Companies***, including any size aircraft operated commercially for hire to carry passengers or cargo, e.g., helicopters carrying industrial loads.

    Benefits - Charter aircraft companies that provide passenger or cargo services would benefit the same as similar scheduled airservices (see 6, 7 and 8). Companies providing services similar to Business Aircraft would get similar benefits (see 9). The unique aspects of this segment is the carrying of industrial loads. NASA has had R&D activities specifically addressing helicopters carrying heavy military and civilian loads. Technology for safer operations at low altitudes would also benefit this segment.

    10.1 **Financial** - measure for helicopter cargo carrying: direct operating cost (DOC) per available ton-mile (ATM).

    10.2 **Performance** - measures: maximum lift weight; and, precision placement of payloads.

11. ***Law Enforcement Agencies***, including local, state and federal government. Helicopters are the main aircraft used in this segment, although some GA aircraft are involved.

    Benefits - Any GA aircraft benefits would be similar to Business Aircraft segment (see 9). NASA R&D that improves helicopter acquisition or operating costs would benefit this segment the same as any segment operating helicopters. The unique aspects are technologies for safer operations at low altitudes in metropolitan areas and operations in poor weather.

12. ***Emergency Airlift Organizations***, including private and local, state and federal government. Helicopters are the main aircraft used in this segment, although some GA aircraft are involved.

    Benefits - Same as 11.

13. ***Private Aircraft Owners*** using aircraft for personal travel and recreation.

    Benefits - Same as 9 except cost savings due to efficient operations is general not an important factor.

    13.1 **Financial** - measure: purchase price; and, direct operating costs (DOC) per mile.

c. Federal Aviation Administration.

NASA performs R&D in several areas that directly impact FAA responsibilities in aviation safety and air traffic management and in technologies that FAA would have to certify to be used in the national airspace. The benefits, however, accrue not to FAA but to the other segments of the aviation community and public discussed in these paragraphs. One might argue that NASA has better technical capabilities than FAA, in some cases, and hence is more effective than FAA would be in performing the R&D, and, as such, saves FAA resources. On the other hand, FAA often indicates that NASA is wasteful of Government resources by pursuing technologies or concepts that are not pactical to implement within the national airspace. It seems reasonable to accrue most benefits directly to the end user or beneficiary. i.e., airlines, the traveling public, etc.

Benefits - Research and technology that might directly reduce FAA capital expenditures for facilities or equipment or reduce operating costs. For example, if automation aides developed by NASA allowed a reduction of the number of air traffic controllers required, that savings in operating costs should be considered as a direct cost savings benefit to FAA.

Financial - measures: FAA operating cost savings; and investment reduction.

d. US Citizens

14. ***Aircraft Passengers***, including commercial long-haul and commuters (helicopters as well as fixed-wing), charter aircraft and business aircraft.

    Benefits - NASA R&D that improves flight safety, benefits all passengers of the class of aircraft for which the safety is improved, regardless as to whether the passengers perceive the benefit or not. Other potential benefits of NASA R&D include: lower airfares (due to improved aircraft or operational efficiency, if passed on to the passengers); fewer delays due to air traffic or weather; and, improved passenger environment (noise, ride, etc.). Note that benefits to passengers generally would be in addition to benefits accrued to the aviation community from the same technology. For example, lower airfares are likely to result in more air travel, which benefits the air-carriers, and increases the demand for aircraft, which benefits the manufacturers and suppliers. Fewer delays, reduces the air-carrier's operating costs and lessens the frustration of passengers, which encourages more air travel. Reducing delays has a financial benefit to business travelers as well. It would be difficult to construct measures for a model that effectively account for such benefits as improved passenger environment or reduced frustration from fewer delays.

    14.1 **Financial** - measures include: average ticket price per trip; business cost avoidance due to delays.

15. ***Recipients and Users of Aircargo***, including people who do not realize that the goods purchased arrived by aircargo.

Benefits - NASA R&D that would reduce aircargo operating costs, should benefit aircargo recipients and users because competition would force the savings to be passed on to the customers.

15.1 **Financial** - measure: cost of air-delivered packages; and, cost of products transported by aircargo.

16. ***Aeronautics Industry Employees***, including major aircraft, engine, systems, subsystems, avionics, and component manufacturers and related consulting companies and individuals.

Benefits - The potential benefits to the employees are stable employment, career growth and adequate total compensation, through a stable and, preferably, growing US aeronautics industry. To the degree NASA R&D investments makes US companies and their products more competitive on the world market and/or helps increase the demand for aircraft, the employee will benefit from those investments.

16.1 **Employment** - measures: number of US aeronautics industry employees; and, average total compensation per non-management employee.

17. ***Aviation Community Employees***, including airlines, commuters, travel agencies, cargo carriers, charters, business aircraft operators, and related government agencies, consulting companies and individuals, professional societies and associations.

Benefits - The potential benefits to the employees are stable employment, career growth and adequate total compensation, through a healthy and, preferably, growing aeronautics and aviation industries. To the degree NASA R&D investments helps increase the demand for aircraft and/or air transportation, the employee will benefit from those investments.

17.1 **Employment** - measures: number of US aviation community employees; and, average total compensation per non-management employee.

18. ***General Public.***

Benefits - US citizens benefit from a healthy civil aeronautics and aviation industry because of the positive impact on the US economy and increased tax base; and from positive balance of payments from foreign sales.

18.1 National - measures: total taxes paid by aeronautics and aviation community; and balance of payments from the aeronautics industry.

2.2.1.2 *Military Applications*

a. Aeronautics Industry.

19. ***Airframe Manufacturing Companies***, including military transports, tactical and strategic fixed- and rotary-wing aircraft, and utility aircraft.

Benefits - All US military airframe manufacturing companies can potentially receive the following benefits depending on whether the NASA R&D is applicable to their products, i.e., fighters, bombers, transports, reconnaissance, helicopters, utility aircraft, etc.:

19.1 **Financial** - measures include: net profit; sales; market share; and ROI. Sales include foreign as well as US military sales. These are the most direct benefits and quantifiable, although the contribution of NASA R&D to the final benefits may be difficult to trace and quantify.

19.2 **Unique Facilities** - measure: investment reduction. Same as 1.2

19.3 **Staff Capabilities** - measure: investment reduction. Same as 1.3

20. ***Engine Manufacturing Companies***, including turbojet and turbofan engine companies (GE, P&W, Garrett Engine Division of AlliedSignal, Allison Gas Turbine Division of General Motors and Textron Lycoming), turboprop engine companies (Garrett Engine Division of AlliedSignal, Allison Gas Turbine Division of General Motors and GEAE Small Aircraft Engine Operation), and piston engine companies for utility aircraft (Textron Lycoming, Williamsport Plant, others?).

Benefits - All US aircraft engine manufacturing companies can potentially receive the following benefits depending on whether the NASA R&D is applicable to their products, i.e., turbojets, turbofans, turboprops or piston engines:

20.1 **Financial** - measures include: net profit; sales; market share; and ROI. Same as 19.1.

20.2 **Unique Facilities** - measure: investment reduction (IR_F). Same as 1.2.

20.3 **Staff Capabilities** - measure: investment reduction (IR_S). Same as 1.3.

21. ***Subsystems Companies***, including electrical, hydraulic and pneumatic power and distribution systems, actuation systems, environmental control systems, fuel management systems, engine control systems, landing gear systems, nose-wheel steering systems, braking systems including wheels and tires, anti-icing systems, oxygen systems, escape systems, and others.

Benefits - Subsystems technology is generally not a major part of NASA R&D programs. There have been programs on brakes and tires, anti-icing, landing gear systems, engineer controls, actuation systems, and others but support for such R&D is spotty. When NASA has subsystems technology programs, the following benefits are applicable to that part of the industry:

21.1 **Financial** - measures include: net profit; sales; market share; and ROI. Same as 19.1.

21.2 **Unique Facilities** - measure: investment reduction. Same as 3.2.

22. ***Avionics Companies,*** including guidance and navigation systems, flight control augmentation systems and autopilots, automatic landing systems, flight management systems, cockpit instruments, communications systems (voice and data-links), radar systems, and others.

Benefits - NASA has a long history of R&D in avionics and related technologies in controls, flight management, human factors, and air transportation. When NASA has avionics technology programs, the following benefits are applicable to that part of the industry:

22.1 **Financial** - measures include: net profit; sales; market share; and ROI. Same as 19.1.

22.2 **Unique Facilities** - measure: investment reduction. Same as 4.2.

22.3 **Staff Capabilities** - measure: investment reduction. Same as 4.3.

23. **Aircraft Deployed Weapons Companies**, including all offensive and defensive weapons carried on military aircraft.

Benefits - NASA R&D has indirect benefits from weapons integration with the airframe and simulation studies of weapon systems effectiveness, which indirectly affect the weapons market.

23.1 **Financial** - measures include: net profit; sales; market share; and ROI. Same as 19.1.

24. ***Other Suppliers*** including all the components required for aircraft, systems and subsystems manufacturing that are obtained out-of-house.

Benefits -Same as 5.

b. DoD Aviation Segment

25. ***Air Force, Navy, Army, and ARPA Research and Development Organizations***, that perform collaborative programs with NASA or depend on NASA R&T capabilities.

Benefits - NASA provides expertise and facilities required by DoD. If NASA does not provide these capabilities, DoD or industry would have to develop similar capabilities.

25.1 **Financial** - measures: system RDT&E costs savings; operating cost savings; and investment reduction.

26. ***Air Force, Navy, and Army Operational Commands*** that operate and maintain aircraft containing or derived from NASA R&D.

Benefits - The benefits are specific to the service operational requirements. NASA technology has contributed to improved aircraft performance, maneuverability, controllability, obserability, maintainability, and weapon systems effectiveness.

26.1 **Financial** - measures: operating cost savings.

26.2 **War Fighting Capabilities** - measures (typical): max speed and altitude; air combat exchange ratio; max controllable angle-of-attack; flying qualities; radar cross section; minimum take-off and landing distance; etc.

c. US Citizens

27. ***Aeronautics Defense Industry Employees***, including major aircraft, engine, systems, subsystems, avionics, component and weapons manufacturers and related consulting companies and individuals.

Benefits - NASA R&D has much less impact on employment in the defense industry than on the civil side. The demand for military aircraft and hence employment opportunities are driven by international events and not technology. There are some potential benefits of NASA R&D in making US military aircraft more competitive on the world market, given that the US is developing a new aircraft.

28. ***DoD Aviation Community Employees***, including both military and civilian who operate, maintain or support military aircraft.

Benefits - Same as 27.

29. **General Public.**

Benefits - US citizens benefit first from NASA's contributions to national security and second from a healthy military aeronautics and aviation community because of the positive impact on the US economy and increased tax base; and from positive balance of payments from foreign sales. It would be difficult to define a simple measure for NASA's aeronautics contributions to national security that could be used in a model for comparison with other measures discussed here.

Although of lessor importance, measures for the financial benefits to US citizens can be defined.

29.1 **National Security** - measures: reduced armed conflicts involving the U.S.; others?

29.2 **Financial** - measures: total taxes paid by the military aeronautics and aviation community; and balance of payments from the aeronautics industry.

2.2.1.3 *Universities*

a. Faculty

Benefits - NASA supports engineering departments with aeronautics and related disciplinary courses through research grants and contracts.

Financial - measures: faculty salaries; % of salaries paid by NASA funding.

Other - measures: number of faculty in engineering departments with aeronautics and related disciplinary programs.

b. Students

Benefits - NASA research grants and contracts directly support students in aeronautics and related disciplines and indirectly by supporting the faculty and providing research facilities.

Financial - measures: student support funding from NASA

Other - measures: number of students in engineering departments with aeronautics and related disciplinary programs.

c. Institution

Benefits - NASA research grants and contracts provide research facilities for aeronautics and related disciplinary courses and help support the university infrastructure through the overhead applied to grants and contracts.

Financial - measures: facilities funding from NASA sources; overhead received for NASA funding sources.

2.2.2 Technology Investments

2.2.2.1 *NASA Investment*

The NASA investment includes the following:

- R&D funds:
  - R&T Base
    - R&T programs (including University programs)
    - Facilities operations support
    - On-site contractor personnel
  - Focused R&D programs
    - Partnerships and contracts with Industry
    - On-site contractor personnel
    - Technology transfer
- MS (Mission Support) funds:
  - Civil Service Personnel
    - R&D personnel
    - Management and Administrative personnel
  - NASA Infrastructure
  - R&D Facilities operations support
- CoF funds:
  - Construction of Facilities

2.2.2.2 *Other Government Investments*

Other investment that should be included in determining the total investment in a technology are:

- Interagency programs:
  - Co-funded projects to industry
  - Joint programs, each paying own way
  - Other Agency funding NASA R&D facilities/systems
  - DoD assigning aircraft to NASA without "cost" to NASA
  - Other Agency providing operational support/materials
- International programs.

FAA or DoD investments required to implement the technology.

2.2.2.3 *Industry Investments*

Industry typically conducts additional R&D on the technology with IRAD or company funds before selecting the technology for a product. Additional RDT&E investments are required to incorporate it into the product. Industry's investment can exceed the Government investment in some cases. In determining the payoff of one technology vs another, industry investment should be taken into account in some manner.

2.2.3 Subsonic Transport Aircraft Metrics

Determining valid and the most effective metrics for each segment requires an assessment of the benefits and measures discussed in 2.2.1 and the investments discussed in 2.2.2. The objective should be to select the fewest number of benefit measures that can best represent the primary discriminators in determining the highest payoff areas. The second objective should be to have the fewest qualitative metrics as possible without neglecting important factors. If possible one should avoid selecting quantitative metrics that are difficult to estimate the parameters needed to calculate metric values. For example, it is often difficult to estimate industry's investment required to commercialize a technology. It would be better to select a metric which includes that investment as part of their cost of sales.

After assessing all the potential benefits from NASA investment in subsonic transport aircraft technologies, the best measures for determining the highest payoff areas seem to be: 1) % reduction in DOC/ASM; 2) % reduction in DOC/ATM; 3) balance of trade; 4) safety issues; and, 5) environmental issues. The main reasons for the first two are that they are primary measures for the user community, and are relative indicators of the benefits accrued to other stakeholders, and can be quantitatively related to the technologies. If a company develops a product that reduces DOC/ASM and/or DOC/ATM, that company has the potential to benefit from all the measures discussed in 2.2.1. Reduced DOC/ASM and/or DOC/ATM can be passed on to the public in terms of lower cost tickets or cargo costs.

Other financial measures, such as net profit, ROI, cash flow, etc. from sale of products containing new technology from NASA investments, all suffer from the inability to quantitatively relate the technology to the benefit, unless the product is uniquely derived for the new technology. For example, how would a company's net profit, ROI or cash flow from the sale of a new transport aircraft or engine be related directly to any of the several new technologies included in those products? How would the benefits be prorated across the several products?

2.2.3.1 *DOC/ASM and DOC/ATM Metrics*

DOC/ASM and DOC/ATM are suggested as the best financial measures of benefits, but some measure(s) of the investment needs to be incorporated in order to have metrics. The industry investment to commercialize the technology is included in DOC as part of capital investment depreciation (the manufacturing industry would pass their investment costs on to the buyer as part of the product price). Since these metrics will only be used to select the highest payoff technology areas within this segment, one needs only develop a measure of the relative Government investments for each technology. The following is suggested as the relevant Government investment (GI) for each technology program:

$$\begin{aligned} GI = \; & [(\text{direct R\&D\$} + \text{direct MS\$}) \times (1 + \text{Overhead Rate}) + \\ & (\text{Pro-rated facilities capital investment amortization costs})]_{NASA} \\ & + [(\text{direct systems implementation \$}) \times (1 + \text{Overhead Rate})]_{FAA} \end{aligned} \tag{1}$$

where the NASA and FAA Overhead Rates are the costs of all the non-direct functions divided by the NASA or FAA budgets respectively. Direct $ in this context means all R&D $ and MS $ that are identifiable to technology programs, mission operations or systems implementation.

Table 2 U.S. Major Carriers Systemwide Aircraft Block-Hour Operation Expenses - Narrowbody Aircraft ($ per Bolck-Hour)

(from Reference 3)

	Flying Operations					Total	Direct Maintenance			Total				Total	Block
Narrowbody	Crew Cost	Fuel & Oil	Rentals	Insur.	Taxes	Flying Ops. Cost	Airframe	Engines	Burden	Maint. Cost	Deprec	Total DOC	Other	Ops Cost	Hours Flown
A320-1/200	**455**	**426**	**529**	**22**	**26**	**1,460**	**93**	**57**	**81**	**232**	**96**	**1,788**	**21**	**1,808**	**319,181**
America West	252	442	813	41	19	1,567	134	27	118	279	41	1,887	35	1,922	73,905
Northwest	504	418	387	17	25	1,352	83	80	46	209	126	1,687	20	1,707	196,495
United	572	438	671	13	41	1,734	72	12	168	251	58	2,043	5	2,046	48,781
B727-200	**705**	**676**	**57**	**6**	**37**	**1,482**	**171**	**114**	**285**	**570**	**140**	**2,192**	**51**	**2,243**	**1,085,848**
American	724	688	67	14	33	1,529	145	84	208	437	124	2,090	90	2,180	304,098
Delta	800	664	54	2	32	1,552	143	148	281	572	92	2,216	41	2,257	415,098
TWA	410	838	44	8	25	1,128	137	117	286	550	152	1,830	6	1,834	145,328
United	893	708	58	3	59	1,521	284	88	392	764	246	2,531	44	2,575	221,326
B737-1/200	**538**	**428**	**227**	**5**	**20**	**1,208**	**136**	**112**	**170**	**418**	**87**	**1,713**	**42**	**1,765**	**812,882**
Delta	583	418	489	5	21	1,515	116	71	210	397	31	1,943	60	1,994	193,655
Southwest	323	422	171	8		926	110	145	31	286	138	1,350	16	1,365	196,348
United	603	448	241	1	39	1,231	158	111	208	475	100	1,806	2	1,808	182,855
USAir	669	429	50	8	20	1,175	157	119	221	497	114	1,786	89	1,878	239,724
B737-300	**443**	**417**	**403**	**12**	**18**	**1,293**	**176**	**98**	**161**	**435**	**99**	**1,827**	**16**	**1,843**	**1,364,153**
Continental	320	394	458	13	17	1,200	173	72	98	342	61	1,603	33	1,838	219,384
Southwest	324	428	177	8		938	173	163	32	388	138	1,464	13	1,457	401,914
United	492	423	567	9	36	1,627	168	45	282	475	105	2,207	3	2,110	372,021
USAir	696	412	463	19	19	1,500	189	98	239	624	74	2,198	16	2,114	370,834
B737-400	**834**	**421**	**585**	**20**	**18**	**1,589**	**78**	**64**	**49**	**188**	**85**	**1,862**	**4**	**1,887**	**269,768**
Alaska	421	412	838	14	13	1,698	126		93	218	40	1,956		1,947	74,507
USAir	577	425	502	23	20	1,548	67	95	32	184	102	1,834	3	1,837	195,258
B737-500	**366**	**400**	**223**	**14**	**25**	**1,048**	**139**	**64**	**188**	**381**	**142**	**1,571**	**39**	**1,590**	**346,668**
Continental	14	362	713	3	15	1,107	82	13	29	104	19	1,230	1	1,230	42,112
Southwest	327	428	173	9		937	125	127	32	284	140	1,361	12	1,373	100,739
United	493	395	146	19	39	1,091	161	44	247	432	169	1,692	61	1,773	203,717
B757-200	**631**	**543**	**429**	**14**	**35**	**1,853**	**99**	**165**	**178**	**442**	**214**	**2,509**	**38**	**2,348**	**1,109,367**
American	594	578	402	10	28	1,813	122	108	128	354	252	2,419	41	2,260	297,026
Delta	837	511	411	15	26	1,600	78	266	188	512	207	2,319	16	2,336	337,487
Northwest	522	523	394	18	35	1,381	77	164	90	331	58	1,770	101	1,881	129,966
United	698	662	522	16	60	1,838	108	117	267	492	249	2,579	24	2,603	344,908
DC-9-10	**426**	**384**	**31**	**1**	**26**	**867**	**188**	**93**	**213**	**492**	**48**	**1,407**	**8**	**1,411**	**76,484**
Northwest	474	385	13	1	31	903	214	98	197	509	37	1,449	6	1,465	58,862
TWA	287	378	84	4	9	765	107	78	258	443	79	1,287		1,266	19,822
DC-9-30	**464**	**428**	**80**	**3**	**23**	**989**	**174**	**114**	**243**	**631**	**45**	**1,665**	**27**	**1,692**	**667,663**
Continental	319	442	178	3	19	962	207	118	131	464	24	1,450	6	1,446	108,934
Northwest	467	421	58	3	31	968	111	66	188	345	45	1,358	7	1,364	232,558
TWA	273	407	130	4	14	836	137	76	314	529	15	1,380	20	1,399	109,314
USAir	619	439	28	4	20	1,111	245	184	349	778	73	1,962	64	2,026	208,857
DC-9-40	**420**	**449**	**366**	**6**	**31**	**1,202**	**138**	**104**	**183**	**425**	**128**	**1,755**	**1**	**1,816**	**46,609**
Northwest	463	440	402	6	36	1,335	131	110	136	376	165	1,876	1	1,888	37,826
TWA	274	437	208	5	18	944	187	78	393	638	8	1,590		1,590	8,683
DC-9-50	**474**	**489**	**94**	**4**	**32**	**1,073**	**177**	**113**	**189**	**479**	**80**	**1,632**	**57**	**1,669**	**130,865**
Northwest	458	474	36	4	38	1,010	202	124	167	493	72	1,575	76	1,860	98,319
TWA	621	453	274	3	14	1,287	99	79	269	437	24	1,748		1,727	32,046
F-100	**611**	**338**	**58**	**17**	**17**	**1,041**	**126**	**40**	**67**	**232**	**381**	**1,654**	**13**	**1,637**	**339,395**
American	605	335	44	18	18	1,021	100	22	81	203	412	1,636	17	1,654	217,301
United	623	338	83	14	17	1,076	169	72	43	283	242	1,601	6	1,807	122,094
MD-80	**489**	**476**	**301**	**12**	**24**	**1,313**	**125**	**75**	**137**	**337**	**132**	**1,782**	**31**	**1,813**	**1,779,233**
American	633	481	283	13	24	1,315	134	70	148	360	149	1,824	24	1,838	928,579
Continental	320	470	393	11	20	1,215	193	119	128	440	41	1,696	61	1,757	280,911
Delta	593	472	300	11	24	1,399	62	46	122	260	176	1,835	12	1,837	427,786
TWA	343	475	372	10	28	1,231	80	116	148	341	70	1,642	59	1,701	161,937

Table 3 U.S. Major Carriers Systemwide Aircraft Utilization Per Day - Narrowbody Aircraft

(from Reference 3)

Narrowbody	Aircraft Operated Per Day	Average Aircraft Operations Per Day: Departures	Block Hours	Flight Hours	Miles	RPMs	ASMs	Average Seats Per Flight	Average Stage Length	Operating Cost Per ASM (¢)
A320-1/200	**80**	**4.2**	**10.9**	**9.4**	**4,184**	**407,232**	**617,634**	**148**	**990**	**3.19**
America West	17	5.1	11.5	10.2	4,586	455,391	678,715	148	896	3.31
Northwest	60	4.0	10.8	9.2	4,100	390,289	608,720	148	1,028	3.02
United	13	3.9	10.4	8.8	3,965	407,852	589,604	144	1,007	3.72
B727-200	**363**	**4.3**	**8.5**	**6.9**	**3,008**	**279,671**	**437,125**	**145**	**695**	**4.34**
American	97	4.0	5.6	7.1	3,126	288,304	468,896	150	779	4.00
Delta	136	4.3	8.9	7.2	3,024	258,936	405,192	134	705	4.02
TWA	45	4.0	10.8	9.2	4,100	390,289	808,720	148	1,028	3.02
United	75	3.9	8.1	6.7	2,960	298,861	434,889	147	753	4.79
B737-1/200	**259**	**6.3**	**8.6**	**7.0**	**2,705**	**190,866**	**302,201**	**112**	**428**	**5.04**
Delta	58	6.2	9.2	7.3	2,920	179,991	308,606	108	474	5.95
Southwest	60	8.9	8.7	8.1	3,148	260,071	368,004	120	387	3.42
United	69	4.8	7.4	6.0	2,281	188,884	248,000	109	471	5.39
USAir	77	6.1	8.5	8.0	2,501	174,422	265,888	110	427	6.04
B737-300	**357**	**6.4**	**10.5**	**8.7**	**3,838**	**310,783**	**473,622**	**130**	**572**	**4.19**
Continental	58	6.0	10.3	8.3	3,398	253,931	439,309	129	571	3.65
Southwest	97	9.4	11.4	9.3	3,760	338,725	512,699	137	398	3.24
United	101	4.7	10.1	8.5	3,666	308,622	463,422	126	781	4.59
USAir	101	5.1	10.1	8.5	3,535	293,691	452,501	128	688	4.70
B737-400	**73**	**5.3**	**10.1**	**8.5**	**3,521**	**322,619**	**506,894**	**144**	**666**	**3.72**
Alaska	19	5.6	10.7	9.2	3,775	332,494	523,420	139	674	3.97
USAir	54	5.2	9.9	8.3	3,432	318,990	501,045	146	662	3.83
B737-500	**93**	**8.2**	**10.2**	**8.5**	**3,530**	**268,023**	**383,389**	**111**	**570**	**4.12**
Continental	11	5.4	10.1	8.4	3,468	225,326	362,394	105	645	3.44
Southwest	25	9.4	11.1	9.3	3,667	311,388	447,341	122	389	3.41
United	57	4.9	9.8	8.2	3,483	257,873	376,086	108	703	4.61
B757-200	**284**	**3.8**	**10.7**	**9.2**	**4,236**	**516,157**	**785,578**	**186**	**1,103**	**3.19**
American	79	3.3	10.4	8.9	4,140	482,969	777,792	188	1,259	3.01
Delta	84	4.9	11.0	9.3	4,152	489,050	751,397	161	854	3.42
Northwest	33	3.9	10.8	9.2	4,175	522,882	788,137	184	1,080	2.64
United	88	3.4	10.7	9.4	4,439	570,962	834,432	188	1,319	3.35
DC-9-10	**29**	**5.5**	**7.3**	**5.5**	**2,022**	**86,039**	**151,982**	**76**	**367**	**6.72**
Northwest	22	5.5	7.0	5.4	1,958	84,788	152,587	78	352	6.73
TWA	7	5.4	7.8	6.1	2,230	89,999	150,068	67	418	6.70
DC-9-30	**217**	**5.9**	**8.3**	**6.6**	**2,486**	**147,136**	**248,312**	**100**	**423**	**6.32**
Continental	32	7.1	9.3	7.2	2,801	174,829	293,555	105	398	4.80
Northwest	77	5.2	8.3	6.6	2,584	153,254	258,408	100	498	4.37
TWA	36	5.3	8.4	6.6	2,501	136,042	225,119	90	469	5.23
USAir	72	6.4	7.8	6.1	2,239	134,150	229,502	102	352	6.92
DC-9-40	**15**	**5.2**	**8.6**	**6.9**	**2,706**	**180,332**	**295,842**	**109**	**524**	**5.27**
Northwest	12	5.1	8.7	6.9	2,754	189,631	308,467	112	539	5.23
TWA	3	5.4	8.4	6.5	2,500	151,038	242,498	97	486	5.49
DC-9-50	**41**	**5.6**	**8.6**	**6.7**	**2,594**	**182,887**	**306,380**	**118**	**488**	**4.68**
Northwest	31	5.8	8.6	6.7	2,598	185,418	316,204	122	465	4.48
TWA	10	5.4	8.6	6.7	2,579	175,053	275,968	107	478	5.41
F-100	**111**	**5.4**	**6.4**	**6.7**	**2,626**	**163,832**	**246,842**	**97**	**486**	**6.68**
American	71	5.0	8.4	6.7	2,594	159,318	251,533	97	522	5.52
United	40	8.3	8.4	6.7	2,427	145,402	237,855	98	386	5.69
MD-80	**488**	**4.8**	**10.0**	**8.3**	**3,632**	**303,483**	**489,080**	**138**	**742**	**3.70**
American	260	4.1	9.8	8.2	3,592	312,383	300,149	139	876	3.60
Continental	87	4.7	10.7	8.8	3,831	336,895	538,882	140	817	3.51
Delta	120	6.4	9.8	7.7	3,100	256,144	427,750	138	484	4.19
TWA	42	4.2	10.6	9.0	3,886	328,967	514,638	132	917	3.51

Table 4 U.S. Cargo Carriers Traffic & Financial Summary for 1994*

Carrier	Freight Ton-Miles	Mail Ton-Miles	Total Revenue Ton-Miles	Available Ton-Miles	Cargo Load Factor	Revenue Aircraft Miles	Departures	Total Operating Revenues	Total Operating Expenses
Challenge Air	71,710	901	156,132	315,204	49.5	6,865	5.5	87,376	86,980
DHL	169,227	4,577	249,439	360,845	69.1	21,586	63.4	621,202	597,445
Emery	655,949	201,922	857,882	1,248,064	68.7	35,864	47.2	194,618	187,104
Evergreen	350,129	26,537	384,319	653,159	58.8	9,288	9.1	267,706	271,348
FedEx	4,738,093	51,512	4,789,605	7,678,681	62.4	151,590	281.8	8,998,534	8,399,037
Northern Air	10,804	12,281	23,085	43,665	52.9	3,055	9.7	42,736	33,676
Southern Air	425,877	1,934	427,811	753,519	56.8	12,985	8.3	167,792	157,876
UPS	2,928,162		2,928,162	5,188,131	56.4	89,532	105.0	1,464,306	1,388,185
World	49,395		143,039	335,196	42.7	4,703	1.8	203,010	208,213
Total	9,399,346	299,664	9,959,454	16,576,455	60.1	335,467	532.0	12,047,280	11,329,865

Note: Total Revenue Ton-Miles may include charter activities.

* From Reference 3

The total Government investment for the Subsonic Transport Aircraft segment, GI_{STA} , is the sum of the GI's for all Subsonic Transport Aircraft program elements. Therefore, the suggested financial metrics for the Subsonic Transport Aircraft segment are as follows:

$$\text{(\% reduction in DOC/ASM) x } (1 - GI/ GI_{STA}), \quad \text{and} \qquad (2)$$

$$\text{(\% reduction in DOC/ATM) x } (1 - GI/ GI_{STA}) \qquad (3)$$

where DOC is given by,

$$DOC = \text{(Flying Operations Costs + Burdened Maintenance Costs + Depreciation)} \qquad (4)$$

Tables 2 and 3 present data for 1994 Systemwide Narrowbody Transport Operating Expenses and Aircraft Utilization for major US carriers from Reference 3, as points of reference. Similar data are available for Widebodies. Table 4 presents the 1994 US Cargo Carriers Traffic and Financial Summary from Reference 3, as points of reference.

To use these metrics one needs to estimate the impact of each technology program on the DOC, ASM and ATM for the investment, GI.

It should be noted that the time factor effect on the cost of money has not been addressed in these metrics, as they should be. Both the investments and the cost elements of DOC should be calculated as net present value (NPV). Reference 1, "Aeronautics and Aviation Industry Economic Analysis and Technology Impact", by Lawrence Stern, presents formulae for calculating NPV that are appropriate to use here.

2.2.3.2 *Qualitative Metrics*

Balance of trade is an important measure, independent of the DOC measures, because some technologies would improve the balance of trade while others would not because the would accrue to all users not just US industry, e.g., technology to improved airspace system capacity would reduce DOC for all aircraft not just US manufactured aircraft. This measure is even more difficult to relate to the specific technology programs, therefore, the following qualitative ranking metric is suggested:

Balance of Trade Metric (5)

Ranking	Qualitative Benefit
5	Provides a unique competitive advantage over foreign competitors
4	Helps sell highest value product (airframe) in foreign markets
3	Helps sell high value product (engines) in foreign markets
2	Helps sell lower value products (subsystems, etc.) in foreign markets
1	Possible help in foreign markets
0	No or negative effect on balance of trade

Metrics for safety and environmental issues are also suggested in qualitative ranking formats as follows:

Safety Issues Metric (6)

Ranking	Qualitative Benefit
5	Likely candidate solution to a major safety problem at an acceptable cost
4	Probable safety improvement with minimal implementation and operational costs
3	Possible contribution to improved safety at an acceptable cost
2	Contributes to better understanding of safety issues
1	Implementation will not impact safety
0	Might cause a safety problem

Environmental Issues Metric (7)

Ranking	Qualitative Benefit
5	Likely solution to removing environmental constraints at acceptable cost
4	Probable environmental improvement with minimal implementation and operational costs
3	Possible contribution to meeting environmental constraints at acceptable cost
2	Contributes to better understanding of environmental issues
1	Implementation will not increase environmental problems
0	Might cause a serious environmental problem

Qualitative metrics should only be used if they represent important factors in determining the highest payoff areas that can not be represented quantitatively. For example, if it is possible to develop a quantitative metric for balance of trade that can be related directly to all technology areas within a segment, that should be used instead of (5). If qualitative metrics are necessary, one should try to incorporate some measure of the investment as well.

3.0 MODEL

3.1 Conceptual Model

The multi-dimensional ***potential payoff function*** for NASA's aeronautics investment, denoted by ***PPF***, is given by

$$\boldsymbol{PPF} = \begin{matrix} w1[P1] \\ w2[P2] \\ . \\ . \\ wi[Pi] \\ . \\ . \\ wI[PI] \end{matrix} \qquad (8)$$

where, ***w*i** is the priority weighting factor for the **i**th segment of the NASA Aeronautics Program and, 0 _ ***w*i** _ 1, the value of which is determined by National, political or NASA management priorities; and,

[Pi] is the potential payoff function for the **i**th segment of the NASA Aeronautics Program, e.g., Subsonic Transport Aircraft, Rotorcraft, etc., given by,

$$[Pi] = [(Pi1), (Pi2), ..., (Pij), ..., (PiJ)] \qquad (9)$$

where, **(Pij)** is the value of the **j**th payoff metric for the **i**th program segment, e.g., DOC/ASM, US employment, etc., given by,

$$(Pij) = \begin{matrix} Pij1 \\ Pij2 \\ . \\ . \\ Pijk \\ . \\ . \\ PijK \end{matrix} \qquad (10)$$

where, P_{ijk} is the value of the contribution of the **k**th technology program, e.g., advanced engine technology, air transportation management technology, etc., to the **j**th metric of the **i**th program segment, and is determined from information discussed in section 2.2.

Therefore, for each segment of the NASA Aeronautics Program, e.g., the **i**th segment, the payoff function would be of the form,

$$[\mathbf{Pi}] = \begin{matrix} P_{i11} & P_{i21} & P_{i31} & .... & P_{ij1} & .... & P_{iJ1} \\ P_{i12} & P_{i22} & P_{i32} & .... & P_{ij2} & .... & P_{iJ2} \\ P_{i13} & P_{i23} & P_{i33} & .... & P_{ij3} & .... & P_{iJ3} \\ .... & .... & .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... & .... & .... \\ P_{i1k} & P_{i2k} & P_{i3k} & .... & P_{ijk} & .... & P_{iJk} \\ .... & .... & .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... & .... & .... \\ P_{i1K} & P_{i2K} & P_{i3K} & .... & P_{ijK} & .... & P_{iJK} \end{matrix} \qquad (11)$$

The dimensions **J** and **K**, the total number of metrics and technology programs respectively, are taken here as the total across all segments of the NASA Program for ease of presentation in the model. Each element of (11) the value of the potential contribution of a technology program, **k**, to payoff metric, **j**, for the NASA Program segment , **i**. If a metric or technology is not relevant or of minor relevance to a segment of the NASA Aeronautics Program, the column or row of **[Pi]** would be the null set.

Criteria need to be established for each metric as to what minimum value constitutes that technology program being included as one of the highest payoff areas. The set of criteria will be denoted **(P*)**, given by

$$(\mathbf{P^*})^T = (P_{1^*}, P_{2^*}, ... , P_{j^*}, ..., P_{J^*}) \qquad (12)$$

where, P_{j^*} is the minimum value of the **j**th metric for the technology to be considered among the highest potential payoff areas. The criteria are independent of the program segment, so the subscript **i** is not needed. If the metric P_1 is the reduction in DOC/ASM, the value of P_{1^*} might be 2% of the current level. If the metric is qualitative, such as the rating for the impact of the technology program on US employment or balance of trade, then the corresponding criterion, $P\mathbf{j*}$, would be set at the rating considered to be the minimum for the technology to qualify as one of the highest potential payoff areas by that metric alone.

The set of technology programs considered to provide the highest potential payoff for the **i**th segment, **[Pi]^**, of the NASA Aeronautics Program, are determined by comparing the elements of each of the **K** rows of **[Pi]**, equation (11), to the elements of $\mathbf{(P^*)^T}$. If any element of the **k**th row of **[Pi]** exceeds the criterion of $\mathbf{(P^*)^T}$, then the **k**th technology is included in the set, i.e.,

$$\mathbf{[Pi]\hat{}} \quad = \quad \mathbf{[Pi]} \ \geq \mathbf{[(P^*)^T]} \tag{13}$$

Once this is completed for every segment of the NASA Aeronautics Program, the highest potential payoff areas are determined by

$$\boldsymbol{PPF\hat{}} \quad = \quad \begin{array}{l} \boldsymbol{w}\mathbf{1[P1]\hat{}} \\ \boldsymbol{w}\mathbf{2[P2]\hat{}} \\ . \\ . \\ \boldsymbol{w}\mathbf{i[Pi]\hat{}} \\ . \\ . \\ \boldsymbol{w}\mathbf{I[PI]\hat{}} \end{array} \tag{14}$$

The final step is to apply the priority weighting factors, ***w*i**. If any of the weightings is zero, then that respective segment(s) would be eliminated from ***PPF*^** . Use of priority weighting factors allows the process of estimating the potential payoffs to be determined independent from higher level issues of National and political priorities, which change with administrations and Congressional leadership, and yet the final answer includes those priorities.

Other selection criteria for technology considered in the highest payoff areas than (13), could be used. One could require that a technology program produce payoffs that exceed the minimum criteria for more than one metric to be included; or one could rank-order the metrics in terms of their relative importance for each segment, then rank the technologies with respect to the most important metric; or use a weighted sum of two or more metrics; or just use a logical heuristic criteria for ranking across the metrics. Since there are generally multiple metrics of importance for every segment of the program and the relative importance of these metrics change with time, the way in which the potential payoff function, ***PPF***, is constituted, in terms of metrics and selection criteria, should be adapted to the priorities at the time.

3.2 Subsonic Transport Aircraft Example

An example model for the Subsonic Transport Aircraft technology area (**i** = 1) is developed here to illustrate the concept. No attempt is made to include all technologies or even all metrics that might apply. A representative number of each will be used. The metrics (**j**, with **J** = 3) selected are:

1. (% reduction in DCO/ASM) x (1 - GI/ GI_{STA})
2. Ranking in contribution to Balance of Trade
3. Ranking in safety issues

where the definitions for metrics 2 and 3 are presented in (5) and (6) respectively.

The technology programs (**k**, with **K** = 5) considered are those listed in Subsonic Transport Aircraft section of the "Aeronautical Technologies for the Twenty-First Century" report by the National Research Council (Reference 2):

Technology Programs	Investment ($M)* NASA R&D	NASA Direct MS	NASA Facil.	FAA	GI $	GI %
1. Aerodynamics	12.9	5	6	0	23.9	16.0
2. Propulsion	16.8	3	5	0	24.8	16.6
3. Structures and Materials	28.1	6	2	0	36.1	24.1
4. Controls, Guidance and Human Factors	29.4	7	4	0	40.4	27.0
5. Systems and Operations (including flight systems research and systems analysis)	2.3	2	4	10	18.3	12.2
6. Other (excluded in example)	4.0	2	0	0	6.0	4.0
Total	93.5			$\mathbf{GI_{STA}}$ =	149.5	100.0

*The R&D $ are from reference 2 for 1992. Other $ are hypothetical for illustrative purpose.

To calculate the elements of **[P1]** requires knowledge of the details of each technology program and estimates of their potential contributions to each metric, as discussed in section 2.2.3. For this example, the estimates used are based on information in Reference 2 and the author's experience, and are illustrative only:

P111 = Aerodynamics program contribution to (% reduction in DOC/ASM) x (1 - $GI1/GI_{STA}$)
(due to reduced fuel usage & increased performance)
= 2.25% x (1 - 0.16) = 1.89%

P112 = Propulsion program contribution to (% reduction in DOC/ASM) x (1 - $GI2/GI_{STA}$)
(due to reduced fuel usage, higher reliability and reduced maintenance)
= 5.63% x (1 - 0.166) = 4.7%

P113 = Structures and Materials contribution to (% reduction in DOC/ASM) x (1 - $GI3/GI_{STA}$)
(due to lower weight and longer life)
= 1.13% x (1 - 0.241) = 0.86%

P114 = Controls, Guidance and Human Factors contribution to (% reduction in DOC/ASM) x (1 - $GI4/GI_{STA}$)
(due to higher reliability and reduced maintenance)
= 0.5% x (1 - 0.27) = 0.37%

P115 = Systems and Operations contribution to(% reduction in DOC/ASM) x (1 - $GI5/GI_{STA}$)
(due to reduction in fuel usage from optimum flight paths and increased airspace system capacity)
= 1.5% x (1 - 0.122) = 1.32%

P121 = Aerodynamics program contribution to ranking in Balance of Trade
= 4 (helps airframe companies sell the foreign markets)

P122 = Propulsion program contribution to ranking in Balance of Trade
= 3 (mainly helps engine companies sell engines in foreibn markets)

P123 = Structures and Materials contribution to ranking in Balance of Trade
= 4 (helps airframe companies sell the foreign markets)

P124 = Controls, Guidance and Human Factors contribution to ranking in Balance of Trade
= 2 (helps subsystems companies which are a small part of trade)

P125 = Systems and Operations contribution to ranking in Balance of Trade
= 0 (technology benefits all airlines and not a trade advantage)

P131 = Aerodynamics program contribution to ranking in safety issues
= 1 (new technology used would not impact safety)

P132 = Propulsion program contribution to ranking in safety issues
= 1 (new technology used would not impact safety)

P133 = Structures and Materials contribution to ranking in safety issues
= 1 (new technology used would not impact safety)

P134 = Controls, Guidance and Human Factors contribution to ranking in safety issues
= 3 (possible reduction in accidents due to human errors and new technology and procedures used would not reduce safety)

P135 = Systems and Operations contribution to ranking in safety issues
= 4 (probable reduction in ground operations accidents and new technology and procedures used would not reduce safety)

Therefore,

$$\mathbf{[P1]} = \begin{matrix} 1.89\% & 4 & 1 \\ 4.70\% & 3 & 1 \\ 0.86\% & 4 & 1 \\ 0.37\% & 2 & 3 \\ 1.32\% & 0 & 4 \end{matrix} \qquad (15)$$

The criteria for this exaample is assumed to be the following:

$$\mathbf{(P^*)^T} \quad = \quad \mathbf{(}1.5\%,\ 5,\ 4\,\mathbf{)} \tag{16}$$

with the additional constraint that any technology program must have a ranking in safety issues of at least 1, which all of these programs meet. It would be possible for one to have a 0 ranking in safety issues if, for example, the program contained a safety risk with no risk mitigation plan. Applying the criteria to (16) gives a Subsonic Transport Aircraft potential payoff function of,

$$\mathbf{[P1]^\wedge} \quad = \quad \mathbf{[P1]} \ \geq\ \mathbf{[(P^*)^T]} \tag{17}$$

$$\mathbf{[P1]^\wedge} \quad = \quad \begin{matrix} 1.89\% & 4 & 1 \\ 4.70\% & 3 & 1 \\ 1.32\% & 0 & 4 \end{matrix} \tag{18}$$

In this hypothetical example, the model selected Aerodynamics, Propulsion, and Systems and Operations as the highest potential payoff areas for Subsonic Transport Aircraft and presents estimates of the payoffs with respect to the three metrics, DOC, Balance of Trade and Safety Issues.

4.0 CONCLUSIONS

A multi-dimensional conceptual model for determining the highest potential payoff areas for NASA's aeronautical investments has been developed. It is intended for use in establishing priorities within NASA's R&D budget among proposed programs. The model is a weighted collection of models for each segment of the NASA's proposed program, e.g., subsonic transport aircraft technology, helicopter technology, etc. The weighting factors, with values from 0 to 1.0, are chosen to reflect National and/or political priorities among the program segments. Each segment model can be used to rank the benefits within that program segment. The structure of the segment models is such that a wide variety of quantitative (e.g., reduction in direct operating costs or aircraft purchase price) and qualitative (e.g., safety or environmental issues) metrics may be used that represent the most important factors for that segment. The metrics need not be the same across all segments; however, a selection criterion must be established for each metric to determine which technology programs are among the highest payoff areas. A technology program is selected to be among the highest payoff areas, if the value for any one of the metrics exceed the criterion for that metric. The model is illustrated for the subsonic transport aircraft technology segment.

An extensive discussion of potential benefits to all the stakeholders in NASA R&D and technology investments are presented to assist the user in constructing the most important metrics for each program segment, similar to the example for subsonic transport aircraft.

Examples of how to select metrics that relate to the technology programs and investments are presented.

The model allows the user to select metrics that are the most important for each segment of the NASA aeronautics program and which can be related to the contributions of the technology program, rather than being restricted to one metric, such as net present value of cash flow from future sales of products, that may not apply to all segments and might be difficult to relate to the technology program contributions. Criteria for selection of the potential highest payoff areas may include both quantitative and qualitative metrics. Selection of a technology program is based on any one or more of the metrics for that technology program meeting the respective criterion. For example, a propulsion technology program might be selected for reducing DOC, while an avionics technology program is selected for improving safety.

Ideally, a simple one-dimensional model would be preferred, that includes all technology programs for all segments on one scale using one metric that is easy to calculate. Unfortunately, models that attempt to do that, do not reflect the most important potential payoff metrics of each segment and often ignore segments of the aeronautics program that don’t fit the metric selected. A multi-dimensional model is more complex than one would like, but it is representative of the actual situation that NASA Management faces in setting priorities across the proposed aeronautics program each year.

5.0 REFERENCES

1. Stern, Lawrence H.: "Aeronautics and Aviation Industry Economic Analysis and Technology Impact", to be published as a NASA report, 1995.

2. Anon.: "Aeronautical Technologies for the Twenty-First Century", report of the Committee on Aeronautical Technologies, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington DC, 1992.

3. Anon.: "World Aviation Directory", McGraw Hill, Aviation Week Group, Summer 1994.